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Hybrid Panels of Wood Plies and Particles *Pinus* sp

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Authors' contributions

This work was carried out in collaboration between all authors. Author LBM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author GGB managed the literature searches. Author ALC performed the statistical analysis. Authors FARL and THP managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The aim of this study was to develop a hybrid panel produced with wood plies and wood particles of *Pinus* sp. as an alternative to plywood. Tests were performed to determine mechanical properties in static bending: elasticity modulus and rupture modulus, in addition to physical testing to determine thickness swelling after 24 hours water submersion. These properties were compared with normative documents of plywood (DIN 68792) and OSB (EN 300: 2006). It was possible to conclude that panels produced in this study are in accordance with the minimum requirements of two Normative codes related to evaluated properties, which proves technical feasibility of its production.

Keywords: Hybrid panel; plywood; OSB; particles; Pinus sp.

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1. INTRODUCTION

Wood is considered a versatile material because its characteristics and unique properties allow great possibilities as regards its applicability. Although Brazil presents great biodiversity in its forests, studies point to native wood offer reduction, mainly those with desirable properties for civil construction [1,2,3].

In this context, many researches have been developing related to wood panels, with the aim of making these alternative products replace the use of solid wood and plywood as raw material in different sectors, and some of them can be here mentioned [4,5,6].

In paper [7] it was cited that wood panels are classified according to their production process and type of raw material used: panels made from mechanically processed wood which are made up of layers of solid wood, and panels of reconstituted wood which are manufactured with wood under different disintegration processes.

Plywood is an example of panels based on mechanically processed wood. According to [7] these products are defined as panels formed by a certain quantity of wood plies, bonded to one another with phenolic resins or urea / formaldehyde, forming layers, arranged 90 degrees between them. Plywood had a significant importance in the Brazilian scenario since the 1970s [8]. Its great employability is due to the good mechanical characteristics such as the capacity to withstand impact loads and disruption resistance, what allows its diverse applicability [9].

Oriented Strand Board, better known as OSB, represents a type of reconstituted wood panel that are produced from oriented wood strips (strands), waterproof resin and hot press consolidation. This product presents increasing demand in a crescent number of countries, since it appeared as an alternative of use to plywood due to its lower costs of production, despite the same indications of use than plywood [10]. The lower cost of production of the OSB is due to possibility of wood logs better utilization and use of wood considered of lower quality, such as from forest plantations thinning, thin and tortuous trunks, as well as species of lower commercial value [11,12].

Although OSB be considered plywood successor once presents similar properties, in paper [13] is emphasized that OSB dimensional stability can be a limitation in relation to plywood. The dimensional stability is the ability of a material to maintain its essential or original dimensions while being used for its intended purpose. According to the authors, OSB in contact with high humidity presents significant thickness swelling, higher than plywood, which plies are arranged perpendicular to each other allowing interesting dimensional stability.

In this context, this work is aimed at evaluation at hybrid panel production technical feasibility with external plies and internal particles of same wood species, using polyurethane resin based on castor oil as resin, in order to obtain an alternative product to replace plywood and OSB, with compatible thickness swelling.

2. MATERIALS AND METHODS

This work was carried out at Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering (SET), São Carlos School of Engineering (EESC), University of São Paulo (USP).

Panels were produced based on plies and wood particles of *Pinus* sp. (Fig. 1), with moisture content ranging between 10 and 12% (equilibrium with the environment).

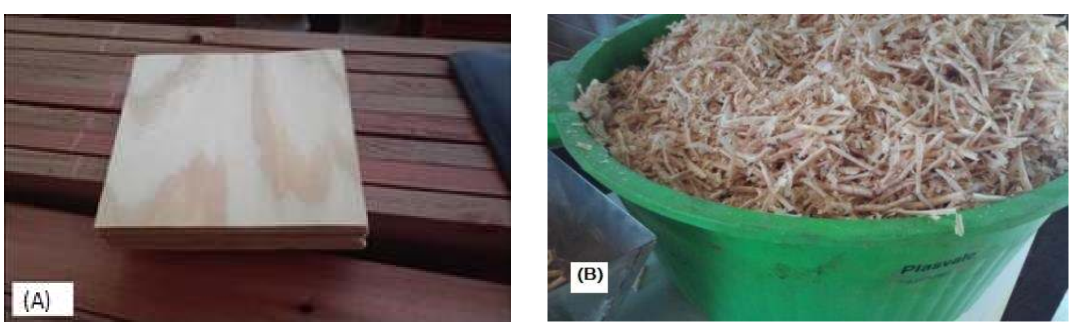

Fig. 1. (A) Wood plies (B) Wood particles

Plies presented initial nominal dimensions 2x400x400 mm and density 0.7 g/cm³. Wood particles were produced (dimensions ranging from 0.6 to 5.5 mm) using a knife mill (Fig. 2), from sawmill residues.

Fig. 2. Knife mill

For each panel produced were used: two *Pinus* sp. wood plies, 360 g of wood particles and 14% of castor oil based as polyurethane adhesive, based on particles dry weight. According to [14], 1:1 ratio (polyol and prepolymer) was adopted to a resin gel time necessary to production process, 26 g of Prepolymer and 26 g of polyol.

Thus, particulate material was directed with the adhesive to a bonding set. Adesive and particles were homogenize for five minutes (Fig. 3).

After this process, the sandwich panel was formed: one *Pinus* sp. ply was placed within a mold, particles already with resin were placed on ply top, then another ply was placed on particles top. The mattress formed was subjected to a pre-pressing performed on a hydraulic press (Fig. 4.) which, according to [15], is a process that allows better conformation and avoid particle loss during panel production process.

The shaped panel was took to a hot hydraulic press, in which the pressing cycle to obtain the hybrid panels was 10 minutes at a pressure of 12 kgf / cm² (1.2 MPa) and a pressing temperature of 100°C. The press used was a semiautomatic machine of the brand Marconi, model MA098 / 50 with 800kN capacity and maximum temperature of 200°C. Five panels were produced, which remained 72 hours in the adhesive curing process after production process. Then, panels were framed (Fig. 5.).

Fig. 3. Bonding set

Fig. 4. Hydraulic press for pre-pressing

For physical and mechanical properties determination, 5 test bodies per panel were initially made for static bending test to determine elasticity modulus and rupture modulus. From static flexural tests bodies already tested, test bodies were produced to determine panel density, thickness swelling and water absorption. Table 1 shows tests performed and normative codes followed. Fig. 6 shows test bodies removal scheme by panel, were represented the panel produced and each sample cut from these panel. Static bending samples in rectangular format and thickness swelling in small squares.

In order to compare hybrid panels produced in this work, the same physical and mechanical tests were performed on commercial panels and OSBs purchased in the wood trade of São Carlos.

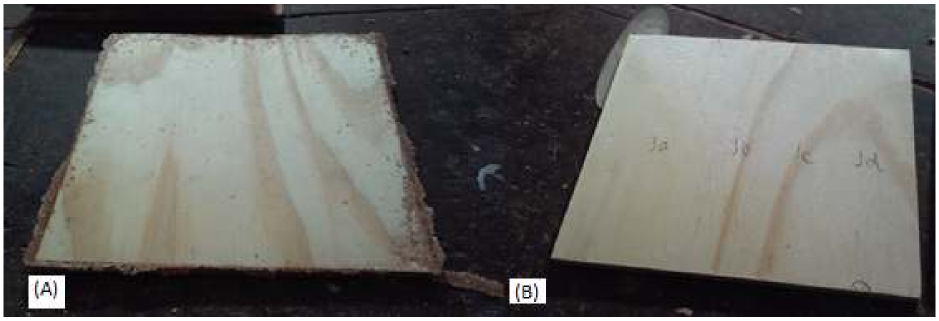

Fig. 5. (A) Panel produced (B) Final panel

Table 1. Samples for each material and types of normative testing

Types of tests	Standard	N°samples/panels	n°of samples	Dimensions
Static bending	EN 310 [16]	5	25	50x250 mm
Thickness swelling	EN 317 [17]	5	25	50x50 mm
Water absorption	EN 3213 [18]	5	25	50x50 mm

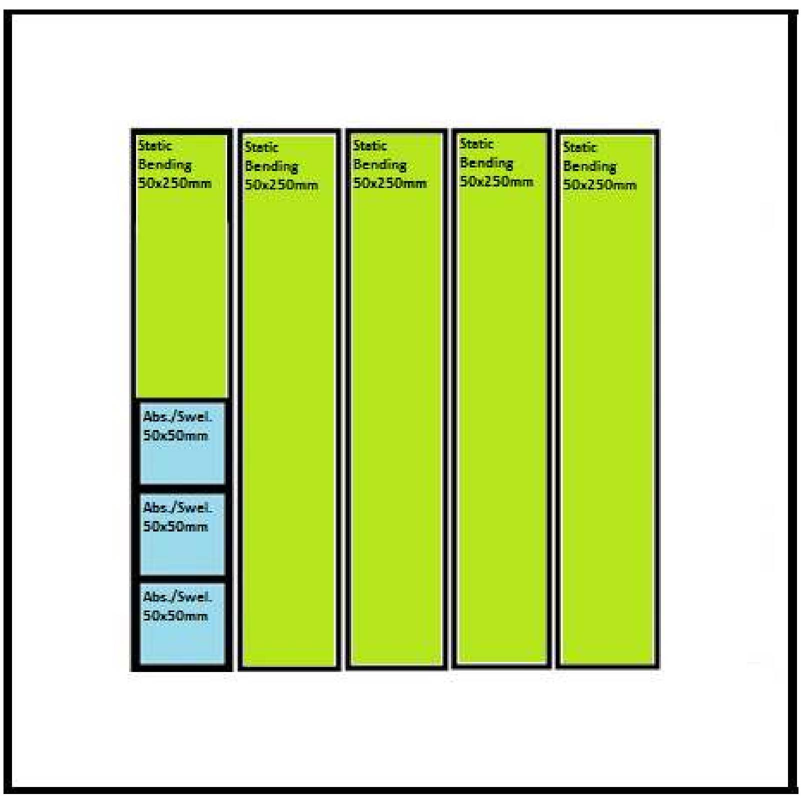

Fig. 6. Panel produced and samples cut from these panel. Static bending samples, 50x250 mm, in rectangular format (green) and thickness swelling and water absorption, both with 50x50 mm, in small squares (blue)

Regarding statistical results analyzes, the type panel influence (commercial OSB [OSB]; commercial plywood [Plyw]; manufactured hybrid panel - particles / plies [Hyb]) in physical and mechanical properties of interest were investigated with the aid of Kruskal-Wallis non-parametric variance analysis (ANOVA) and Student-Newman-Keuls test comparisons were used, considering significance 5% level (α). From ANOVA, null hypothesis (H0) formulated consisted of treatments mean equivalences, and non-equivalence (of at least two) as an alternative hypothesis (H1).

Physical properties evaluated were apparent density (ρ), water absorption after 2 (Abs. 2 h) and 24 hours (Abs. 24 h) immersion in water and thickness swelling after 2 hours (Swel. 2 h) and 24 hours (Swel. 24 h), and mechanical properties evaluated were elasticity (MOE) and rupture (MOR) modulus in static bending. Five hybrid panels [Hyb] (particle-plies) were fabricated, and 5 samples were drawn from each panel. From commercial panels five samples were extracted per test type. In all, 245 determinations were obtained.

3. RESULTS AND DISCUSSION

Tables 2, 3 and 4 present mean values ($\bar{x}$), variation coefficients (VC), smallest (Min) and largest (Max) physical and mechanical properties values by panel evaluated type, and Fig. 7 illustrates Graphs with mean values and confidence intervals of respective response variables investigated.

Table 2. Physical and mechanical properties of hybrid panels (Hyb)

Statistics	ρ (g/cm^3)	Abs. 2 h (%)	Abs. 24 h (%)	Swel. 2 h (%)
$\bar{x}$	590.53	35.36	51.63	6.2396
VC (%)	11.11	19.90	15.52	56.98
Min	485.53	27.86	37.57	0.35
Max	707.71	54.73	71.01	14.21
Statistics	**Swel. 24 h (%)**	**MOR (MPa)**	**MOE (MPa)**	
$\bar{x}$	8.80	48.17	7828	
VC (%)	50.10	23.62	35.9	
Min	1.04	31.34	3776	
Max	17.86	77.70	14709	

Table 3. Physical and mechanical properties of OSB panels

Statistics	ρ (g/cm^3)	Abs. 2 h (%)	Abs. 24 h (%)	Swel. 2 h (%)
$\bar{x}$	601.93	55.74	72.97	10.09
VC (%)	10.30	18.09	16.23	63.28
Min	533.29	44.33	57.55	3.52
Max	673.47	67.21	86.46	18.45
Statistics	**Swel. 24 h (%)**	**MOR (MPa)**	**MOE (MPa)**	
$\bar{x}$	13.81	6.46	4042	
VC (%)	29.08	16.23	32.48	
Min	10.39	5.31	3260	
Max	20.38	7.87	6379	

Table 4. Physical and mechanical properties of plywood panels (Plyw)

Statistics	ρ (g/cm^3)	Abs. 2 h (%)	Abs. 24 h (%)	Swel. 2 h (%)
$\bar{x}$	566.66	46.34	67.67	12.93
VC (%)	10.64	25.88	16.87	26.16
Min	498.04	25.97	49.51	9.32
Max	655.53	54.81	78.99	18.11
Statistics	**Swel. 24 h (%)**	**MOR (MPa)**	**MOE (MPa)**	
$\bar{x}$	14.75	9.86	4510	
VC (%)	23.47	13.20	23.01	
Min	11.33	8.34	3545	
Max	19,80	11,48	5974	

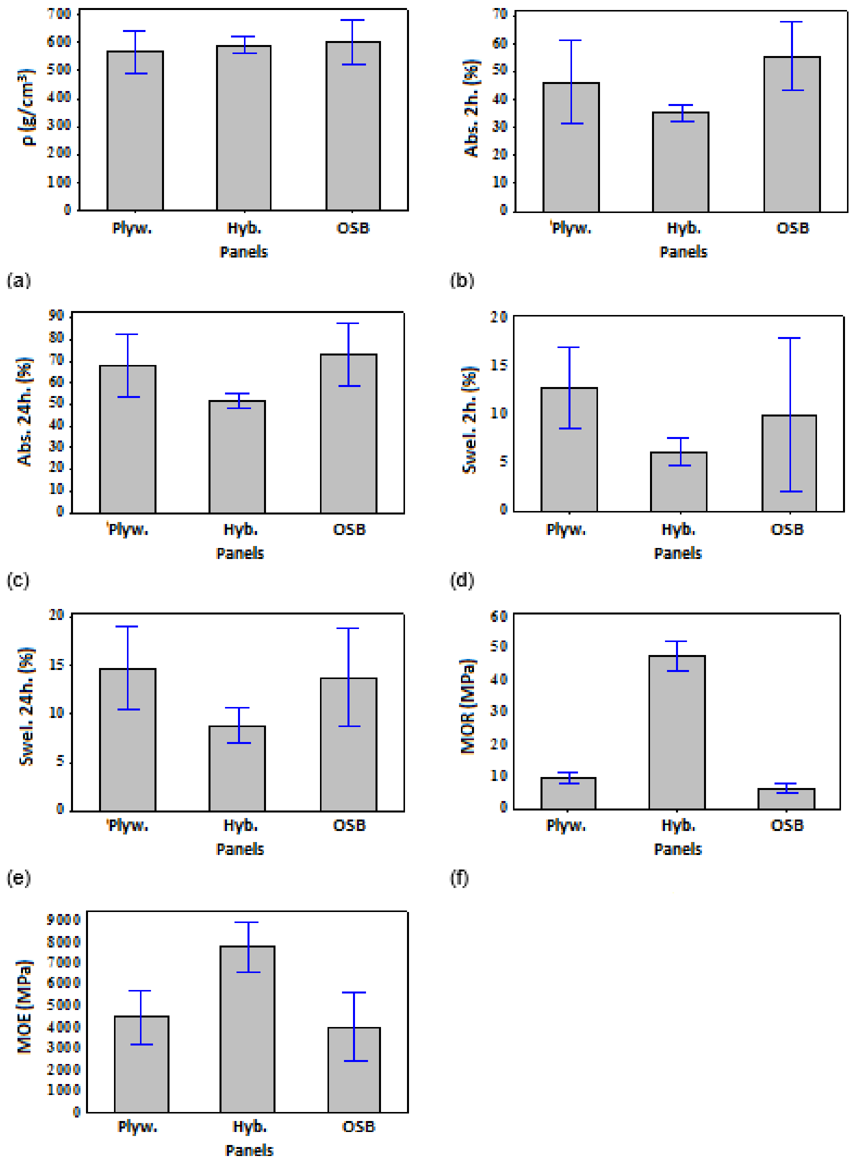

Fig. 7. Mean values and confidence intervals of investigated properties: ρ (a), Abs. 2 h. (b), Abs. 24 h. (c), Swel. 2 h. (d), Swel. 24 h. (e), MOE (f), MOR (g)

Table 5 presents the minimum values required by normative documents for OSB panels and plywood for elasticity and rupture modulus.

It is possible to observe that hybrid panels produced in this work have met the requirements for OSB1, OSB2, OSB3 and OSB4 type panels. Regarding rupture modulus and elasticity modulus established by [20] for plywood panels, almost all hybrid panels produced in this work met the minimum requirements established, leaving only hybrid panel 3 below the value required by this standard for MOR.

The commercial OSB panel was classified as OSB 3 in relation to its elasticity modulus, as for rupture modulus, the panel did not reach the minimum value required by [20] for any of the classes. As for the commercial plywood panel, it did not meet any of the minimum values required by [20], either for elasticity modulus or for the rupture modulus.

Table 5. Minimum values required for OSB and offset panels and their respective normative documents

	MOR	MOE	Swel. 24 h
OSB1 (EN300) [19]	20 Mpa	2500 MPa	25%
OSB2 (EN300) [19]	22 Mpa	3500 MPa	20%
OSB3 (EN300) [19]	22 Mpa	3500 MPa	15%
OSB4 (EN300) [19]	30 Mpa	4800 MPa	12%
Plywood (DIN 68792) [20]	45 Mpa	5000 MPa	

For the 24 hour thickness swelling property, the panels in this study presented values lower than those stipulated by [20] for OSB panels type 1, 2, 3 and 4.

As the commercial OSB panel was classified as OSB1, OSB2 and OBS3 as the property of thickness swelling for 24 hours.

In [21] were studied the properties of plywood panels with five different *Pinus* species and urea-formaldehyde resin. The authors found lower values than those for this work hybrid panels regarding rupture and elasticity modulus, as shown in Table 6. However, Iwakiri et al 's panels produced presented lower thickness swelling when immersed for 24 hours in water, when compared to this work hybrid panels.

Table 6. Demonstrated values of Iwakiri et al. [21]

Wood	MOR	MOE	IE% (24h)
	(X)	(X)	(X)
Pinus caribaea	34.87	3877.34	5.06
Pinus chiapensis	38.28	4223.91	5.49
Pinus maximinoi	39.49	6838.12	5.93
Pinus oocarpa	33.11	6158.93	7.09
Pinus taeda	32.01	4330.27	7.03
Pinus tecunumannii	38.94	5015.48	5.64

In [22] two types of Eucalyptus were used in structural plywood panel production and for glued plies was used phenol-formaldehyde resin. This panels presented MOE and MOR values much higher than hybrid panels in this work (Table 7).

Table 7. Demonstrated values of Iwakiri et al. [22]

Treatment	MOR	MOE
	(X)	(X)
T1-grandis	76.20	123100
T2-grandis	83.70	110580
T3-grandis	80.40	128542
T4-dunnii	75.30	133863
T5-dunnii	77.50	126996
T6-dunnii	73.80	126955

Table 8 shows the results (*P* value) of Kruskal-Wallis ANOVA and the Student-Newman-Keuls (grouping) test of panel type factor for each physical and mechanical property investigated. In Table 8, A denotes the highest average value group, B the second highest average value and so on, and equal letters imply treatments with equivalent means.

From Table 5 it can be seen that panels had equivalent apparent densities, that the lower water absorption values (2 and 24 hours) and thickness swelling (2 and 24 hours) came from hybrid panels manufactured in this work, and the highest values were derived of two commercial panels investigated, which exhibited behaviors equivalent about physical properties.

Table 8. Results of Kruskal-Wallis ANOVA and Student-Newman-Keuls multiple comparisons test of physical and mechanical properties evaluated by panel investigated type

Properties	ANOVA	Comparisons between Student-Newman-Keuls		
		Hyb	OSB	Plyw.
ρ	0.669	A	A	A
Abs. 2h	0.000	B	A	A
Abs. 24h	0.000	B	A	A
Swel. 2h	0.003	B	AB	A
Swel. 24h	0.006	B	AB	A
MOR	0.000	A	B	B
MOE	0.003	A	B	B

From mechanical properties, the highest MOE and MOR values were derived from hybrid panels developed here, followed by the commercial panels, which presented equivalent performances in these two properties.

4. CONCLUSION

The results obtained from the present study allow us to conclude that:

- Hybrid panels presented higher values than those required by [16] for OSB panels type 1, 2, 3 and 4 for MOE and MOR;
- Hybrid panels presented values higher than those required by [20] for panels offset as MOE and MOR, except for the hybrid panel 3 that was lower;
- Hybrid panels presented values lower than those required by [16] for OSB panels for thickness swelling for 24 hours;
- Comparing hybrid panels for MOE and MOR with studies by [21] and [22], panels produced in this work were superior to, first and inferior to the second.
- Regarding the statistical analyzes, it is evident the superiority of the hybrid panels manufactured here in front of the commercial OSB and plywood panels, both in physical properties as in mechanical properties.

Therefore, hybrid panels manufactured in this research have great use potential, presenting physical and mechanical properties with superior performance to commercially available OSB and plywood.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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